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Optimization of Electric Power Systems Modes Under Conditions of Partial Uncertainty of Initial Information Based On use of Payment Matrices

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Abstract. The problem of optimizing the mode of power systems is one of the complex problems of nonlinear mathematical programming. Despite the development of many methods and algorithms for solving this problem over the past few decades, the issues of their improvement, considering the modern operating conditions of energy systems, remain an important task. This article proposes a new algorithm for optimizing short-term power system modes under partial uncertainty of the initial information. A distinctive feature of the algorithm is associated with the elimination of the calculations of the need to select a single intermediate bus with a balancing power plant, which is typical for many existing methods. It is shown that considering frequency changes when optimizing the power system mode and the partial uncertainty of the initial information can significantly change the calculation results and lead to a corresponding increase in the resulting economic effect.

Keywords: Guaranteed savings, power system, optimization of modes, optimal planning, objective function, probability of information, frequency change.

INTRODUCTION

Planning for developing and operating energy systems can be carried out for short, medium, and long-term periods. In planning the development of energy systems, the main goal is to determine the [1-3] most optimal development option, identifying the sources, volumes, and timing [4, 5] of investments in structures. One of the most important tasks to solve before planning [6, 7] is forecasting consumer loads for the upcoming period. This considers population growth rates and the dynamics of other economic indicators.

Planning the development of an energy system is a very complex task with many parameters of various natures, as well as limiting and influencing factors. Planning is divided into static and dynamic planning. Static planning [8, 9] solves the problem for one stage or period; adynamic planning involves solving the problem in several stages.

Another characteristic feature [10, 11] of planning problems for the development and operation of power systems is the uncertainty of the initial information used about the states and properties of the system.

In power systems, uncertainty typically resides in the system's state, the components, and the environment in which an existing state, a future outcome, or more than one possible outcome can be accurately described. Sometimes, uncertainty in such problems leads to deviation of real states and modes from the planned ones and a corresponding loss of reliability and efficiency. In problems of optimal planning for the development of power systems [7, 12, 17], loads of nodes, generated powers, power flows in the circuits of the electrical network, and the states of the elements of the electrical network, usually have uncertain properties. Clearly, uncertainty in the system's operation is more complex and critical than in planning. In systems planning, uncertainty forecasts are usually inaccurate [13], often far from the actual situation, which requires a rough approximation of acceptable uncertainty. Rejection of forecast uncertainty at the planning stage can be “saved” at the operational stage. However, the cost of uncertainty at the operation stage is higher than in planning; therefore, this section of the dissertation discusses the issues of optimizing power system modes during operation - planning short-term power system modes under conditions of uncertainty of the initial information used.

The main initial information, which has a degree of uncertainty or partial uncertainty in the problems [14-16] of optimal planning of short-term modes of power systems, is information about the load graphs [18-27] of nodes and design parameters of networks. The uncertainty of the design parameters - active resistances of power lines, transformers, and other devices is determined by their dependence on the ambient temperature. Typically, they are

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considered by introducing appropriate correction factors based on weather forecast data for the planned period. The uncertainty of node load schedules must be taken into account in the optimization process through the use of special algorithms.

METHOD

The algorithm of optimization

Let us consider the essence of optimization for a typical case, observed in problems of optimization of power system modes, where most often the load is specified in the form of a certain segment $[P_{min};P_{max}]$, within which no probabilistic characteristics are known due to their unknown nature. Moreover, the loads inside the segment are not assigned any probabilistic characteristics since they are unknown. To solve the problem in a given interval, a set of load values is selected $\{P_1, P_2,\ldots,P_n\}$, and $P_1= P_{min}$ and $P_n= P_{max}$. In this case, selecting the number of possible load values in a given range is recommended, considering the required accuracy of solving the optimization problem and the acceptable volume of computational operations performed. Then, the deterministic optimization problem is solved n times for specific accepted load values in a given interval $P_k=\{P_1, P_2,\ldots,P_n\}$. As a result of such calculations, the corresponding optimal values of the sought parameter zk and the values of the objective function are obtained as $B_{kk}=f(z_k, P_k)$. Received $z_k=\{z_1, z_2,\ldots,z_n\}$

form sets of conditionally optimal plans (decisions), and $B_{kk}=\{B_{11}, B_{22},\ldots,B_{nn}\}$ form diagonal elements of the payment matrix of size *nxn*. After this, the values of the objective function are calculated under all possible conditions for the implementation of the obtained conditionally optimal plans, i.e., $B_{kj}=f(z_k, P_j)$ at *k#j*. These objective function values form the non-diagonal elements of the payment matrix. Selecting the best plan among conditionally optimal plans based on using the resulting payment matrix seems impossible without additional criteria. This is because with unknown probabilities of the initial load, different conditions for implementing plans correspond to different values of the objective function B_{ij} and various conditionally optimal plans.

RESULTS AND DISCUSSION

The effectiveness of the described algorithm was investigated. We study the computational qualities of the described algorithm under conditions of partial uncertainty of the initial information using the example of optimization of the power system mode, the diagram of which is presented in Fig. 1. An optimal distribution of the total loads of nodes is required between four thermal power plants located in nodes 0, 1, 6 and 7, with the following consumption characteristics of standard fuel, t.e./h.:

$$B_0 = 100 + 0.2P_0 + 0.002P_0^2 \quad B_1 = 120 + 0.2P_1 + 0.0025P_1^2,$$

$$B_6 = 60 + 0.15P_6 + 0.0015P_6^2, \quad B_7 = 80 + 0.25P_7 + 0.001P_7^2.$$

The total load of the power system is partially uncertain, i.e., only the boundary values are known for it $P_l=[1485\ MW;\ 1815\ MW]$. The capacities of load nodes 2, 3, 4, and 5 are determined by the total load's share coefficients. To solve the problem using the algorithm described above, specified in a given range of an uncertain total load, 5 values were selected at equal intervals, and the corresponding capacities of the load nodes were determined according to the coefficients of their share (Table 1.).

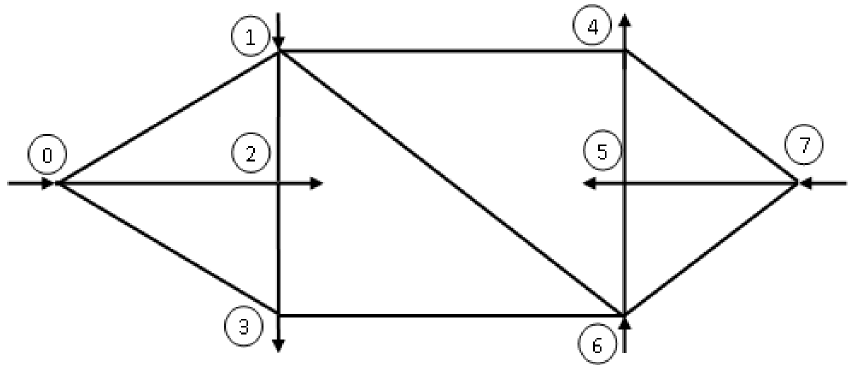

FIGURE 1. Power system diagram

TABLE 1. Possible values of power system loads.

№	1	2	3	4	5
P_l, MW	1485.0	1567.5	1650.0	1732.5	1815.0
P_2, MW	349.0	369.0	388.0	408.0	427.0
P_3, MW	524.0	527.0	582.0	611.0	641.0
P_4, MW	175.0	198.0	194.0	204.0	214.0
P_5, MW	437.0	473.5	486.0	509.5	533.0

By solving the problem of optimizing the power system mode in a deterministic formulation for the known five values of the total load and power of the load nodes (Table 2), conditionally optimal plans for the original problem were obtained (Table 2).

TABLE 2. Conditionally optimal plans obtained as a result of optimal distribution of total power system load between thermal power plants.

Conditional number optimal plan	Total load, MW	Conditionally optimal power of thermal power plants, MW			
		P_0	P_1	P_6	P_7
1	1485	290.91	232.73	404.54	556.82
2	1567.5	306.98	245.58	425.97	588.96
3	1650	323.05	258.44	447.40	621.10
4	1732.5	339.12	271.30	468.83	653.25
5	1815	355.19	284.15	490.26	685.39

Based on the calculation using the algorithm described above, all possible options for implementing the obtained conditionally optimal plans were determined for possible total load values. In this case, imbalances associated with the deviation of the total load of the power system from the value at which this conditionally optimal plan was obtained are covered by a balancing station (for example, to cover the total load of the power system of 1650 MW with the first conditionally optimal plan, which was obtained by the optimal distribution total load is 1485 MW, the power of the balancing station becomes equal to 455.91 MW). In Table 3, the resulting payment matrix is presented, the elements of which represent the total consumption of equivalent fuel at the corresponding TPP capacities.

TABLE 3. Payment matrix.

Conditional number optimal plan	Total load of the power system, MW				
	1485	1567.5	1650	1732.5	1815
1	1524.81	1650.92	1804.26	1984.82	2192.61
2	1535.76	1639.96	1771.38	1930.02	2115.89
3	1568.64	1650.92	1760.41	1897.14	2061.08
4	1623.46	1683.80	1771.37	1886.17	2028.19
5	1700.17	1738.60	1804.25	1897.13	2017.23

Table 4 presents the optimal plans obtained using the criteria described above.

TABLE 4. Optimal plans obtained using various criteria.

Criterion	Conditional number wholesale Planna	Optimal plan (thermal power plant capacity), MW			
		P_0	P_1	P_6	P_7
minimax	5	355.19	284.15	490.26	685.39
minimin	1	290.91	232.73	404.54	556.82
Hurwitz (at α=0.5)	3	323.05	258.44	447.40	621.10
Laplace-Bays	3	323.05	258.44	447.40	621.10
minimax risk	3	323.05	258.44	447.40	621.10

Thus, in the problem under consideration, according to the last three criteria, the third conditionally optimal plan is obtained as optimal. According to the first criterion, 5th, and second criterion, 1st, conditionally optimal plans are obtained as optimal. To assess the effectiveness of the results obtained, a calculation of possible excess consumption of standard fuel was carried out in comparison with its values under the most favorable conditions (obtained by the minimin criterion) and the worst conditions (obtained by the minimax criterion) for the conditions of implementation of the optimal plans obtained according to various criteria:

$$\Delta B_{i,\min} = \min(j)B_{ij} - \min(i)\min(j)B_{ij}, \quad i = 1, 2, ..., 5, \tag{1}$$

$$\Delta B_{i,\max} = \max(j)B_{ij} - \min(i)\min(j)B_{ij}, \quad i = 1, 2, ..., 5 \tag{2}$$

In this problem, the difference between the maximum possible overexpenditure obtained when using the minimin criterion (667.8 t.e.f./h.) and the maximum possible overexpenditure obtained when using the criterion under consideration can be called guaranteed savings for this criterion:

$$\Delta\Delta B_i = \min\min \Delta B_{i,\max} - \Delta B_{i.\max}, \quad i = 1, 2, ..., 5 \tag{3}$$

To compare the results, Table 5 shows guaranteed savings in total equivalent fuel consumption when using various criteria to determine the optimal plan.

TABLE 5. Maximum possible excess fuel consumption from possible deviations of total load of power system, t.e.f./h.

Criterion	Optimal plans	$\Delta B_{i,min}$, t.e.f./h.	$\Delta B_{i,max}$, t.e.f./h.	$\Delta\Delta B_i$, t.e.f./h.
minimax	5	175.36	492.42	175.38
minimin	1	0.0	667.80	0.0
Hurwitz (at α=0.5)	3	43.83	536.27	131.53
Laplace-Bays	3	43.83	536.27	131.53
minimax risk	3	43.83	536.27	131.53

Analyzing the results of the computational experiment, the following conclusions can be drawn:
When using the minimin criterion, the excess consumption of equivalent fuel under the most favorable condition of implementation of the resulting optimal plan is equal to zero, and under the worst condition of implementation - 667.8 t.e.f./h. When using the minimax criterion, these indicators are 175.36 t.e.t./h. and 492.42 t.e.f./h., respectively. When using the remaining three criteria, where the same optimal plans were obtained (3rd conditionally optimal plan), such possible overexpenditures of conventional fuel equal to 43.83 t.e.t./h. and 536.27 t.e.f./h., respectively. Because the maximum guaranteed savings are ensured with the result obtained using the minimax criterion, it is recommended to use this criterion to solve problems of the type under consideration.

CONCLUSIONS

1. An analysis of the effectiveness of algorithms for optimizing power system modes under conditions of partial uncertainty of the initial information was carried out using a payment matrix and various additional criteria.
2. Research shows the feasibility of using the minimax criterion to select the optimal solution among all possible plans.
3. An effective algorithm is proposed for considering functional restrictions in the form of inequalities when optimizing power system modes under partial uncertainty of the initial information based on using the payment matrix and the minimax criterion.

REFERENCES

1. El-Havary, M.E., Christenstn, G.S.: Optimal Economic Operation of Electric Power Systems. Academic Press, New York (1979).
2. Zhu, J.: Optimization of Power System Operation. Wiley-IEEE Press (2015).
3. Bazaraa, M.S., Sherali, H.D., Shetty, C.M.: Nonlinear Programming: Theory and Algorithms. Wiley (2006).
4. Michalewicz, Z., Fogel, D.B.: How to Solve It. Modern Heuristics. pp. 145-487, Springer (2004).
5. Yang, X.S.: Nature-inspired metaheuristic algorithms. pp. 11-108, Luniver Press (2010).
6. Colorni, A., Dorigo, M., Maniezzo, V.: Distributed Optimization by Ant Colonies. In: Proceedings of ECAL91, pp. 134–142. Elsevier Publishing, Paris (1991), pp. 134–142, 1991.
7. Linda Slimani, Tarek Bouktir: Optimal Power Flow Using Artificial Bee Colony with Incorporation of FACTS Devices: a Case Study. International Review of Electrical Engineering (I.R.E.E.), 6(7), November-December (2011), https://www.researchgate.net/publication/289851270
8. Braspenning, P.J., Thuijsman, F., Weijter, A.J.M.M.: Artificial Neural Networks: An Introduction to ANN Theory and Practice, pp.1–100. Springer (1995).
9. Abaci, K., Yamacli, V.: Hybrid Artificial Neural Network by Using Differential Search Algorithm for Solving Power Flow Problem. Advances in Electrical and Computer Engineering 19(4), 57-64 (2019). doi:10.4316/AECE.2019.04007.
10. Pedrycz, W.: Fuzzy control and fuzzy systems, pp. 1–78, John Wiley & Sons (1996).
11. Yang, X.S., Deb, S.: Cuckoo Search via Levy flights. In: 2009 World Congress on Nature & Biologically Inspired Computing, pp. 210–214. IEEE, Coimbatore (2009). doi:10.1109/NABIC.2009.5393690.
12. Pham, D.T., Ghanbarzadeh, A., Koc, E.: The Bees Algorithm A Novel Tool for Complex Optimisation. In: Intelligent Production Machines and Systems, pp. 454-459. Cardiff, UK. Elsevier (2006). doi: 10.1016/B978-008045157-2/50081-X.
13. Pijarski, P., Kacejko, P.: Methods of Simulated Annealing and Particle Swarm Applied to the Optimization of Reactive Power Flow in Electric Power Systems. Advances in Electrical and Computer Engineering 18(4), 43-48 (2018). doi:10.4316/AECE.2018.04005
14. Al-Sumait, J.S., Sykulski J.K., & Al-Othman, A.K.: Solution of Different Types of Economic Load Dispatch Problems Using a Pattern Search Method. Electric Power Components and Systems 36(3), 250-265 (2008). doi:10.1080/15325000701603892.
15. Yuryevich, J., Wong K.P.: Evolutionary Programming Based Optimal Power Flow Algorithm. IEEE Transaction on power Systems, 14(4) (1999).
16. Tarek Bouktir, Linda Slimani, Mohamed Belkacemi: Optimal Power Dispatch for Large Scale Power System using stochastic search algorithms. https://www.researchgate.net/publication/245516225, January 2008, DOI: 10.2316/Journal.203.2008.2.203-3501
17. Allaoua, B., Laoufi, A.: Optimal Power Flow Solution Using Ant Manners for Electrical Network. Advances in Electrical and Computer Engineering 9(1), 34-40 (2009). doi:10.4316/AECE.2009.01006.
18. Valdma, M, Keel, M, Liik, O, Tammoja, H.: Method of Minimax optimization of Power System Operation. In: Proccedings of IEEE Bologna PowerTech 2003, pp. 23-26. Bologna, Italy (2003).
19. Valdma, M, Keel, M. and Liik, O.: Optimization of active power generation in electric power system under incomplete information. In: Proccedings. of Tenth Power Systems Computation Conference, pp. 1171-1176. Graz, Austria (1990).1
20. Gayibov, T.Sh., Latipov, Sh.Sh.: Optimum planning of power modes in conditions of partial uncertainty of background information. Technical science and innovation 2(2), 88-95 (2019).
21. Tulkin Gayibov, Sherxon Latipov, Bakhadir Uzakov: Power System Mode optimization by piecewise-linear

approximation of energy characteristics of Power Plants./ Rudenko International Conference "Methodological problems in reliability study of large energy systems" E3S Web of Conference, 139, 01086. RSES, Irkutsk, Russia (2019). doi: https://doi.org/10.1051/e3sconf/201913901086.

22. Robbins, B.A., Zhu, H. and Domínguez-García, A.D. (2016) Optimal Tap Setting of Voltage Regulation Transformers in Unbalanced Distribution Systems. IEEE Transactions on Power Systems, 31(1), 256-267, doi: 10.1109/TPWRS.2015.2392693.
23. Vadim Manusov, Pavel Matrenin, Nasrullo Khasanzoda. (2019) Power Loss Minimization by Voltage Transformer Turns Ratio Selection based on Particle Swarm Optimization. Przeglad Elektrotechniczny. (8). doi:10.15199/48.2019.08.28.
24. Ramesh, L., Chowdhury, S.P., Chowdhury, S., Natarajan, A.A. and Gaunt, C.T. (2009) Minimization of Power Loss in Distribution Networks by Different Techniques. International Journal of Electrical, Computer, Energetic, Electronic and Communication Engineering, 3(4).
25. Dauren Akhmetbayev, Arman Akhmetbayev, Aigerim Aidarova. (2017) Determination of rational transformation coefficients of transformers distribution networks. E3S Web of Conferences 25, 04003. RSES 2017 . doi: 10.1051/e3sconf/20172504003.
26. Nasyrov, T.Kh., Gayibov, T.Sh. (2014) Theoretical foundations of optimization of power system modes. Fan wa technology. (in Russian).
27. Gayibov, T.Sh. (2014) Methods and algorithms for optimizing the modes of electric power systems. TSTU Publishing House. (in Russian).